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THE SUGAR-TUBE METHOD OF DETERMINING ROCK DUST IN AIR

BY

A. C. FIELDNER, S. H. KATZ, AND E. S. LONGFELLOW

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THE SUGAR-TUBE METHOD OF DETERMINING ROCK DUST IN AIR.

By A. C. Fieldner, S. H. Katz, and E. S. Longfellow.

INTRODUCTION.

In connection with investigations relating to the improvement of health conditions in the mineral industries, the Bureau of Mines has made considerable use of the "sugar-tube method" for determining the nature and amount of siliceous dust in suspension in air. By this method, a measured volume of the dusty air is passed through a tube containing granulated sugar, which filters out the suspended dust. The sugar tube is sent to the laboratory, the sugar dissolved in water, and the insoluble dust filtered off, ignited, and weighed. A portion of the sugar solution containing the dust suspension is made up to a measured volume, and an aliquot part (1 cubic millimeter) is placed under the microscope in order that the number of dust particles may be counted, their size and shape measured, and other characteristics noted. A full description of the method and apparatus previously used are given in Technical Paper 105[1] and Bulletin 132[2] of the Bureau of Mines.

Although this method has been used extensively both in this country and in South Africa, the authors are aware of no critical study heretofore of the efficiency of sugar in removing very fine dust particles, which are probably the most injurious. Indeed, the accurate quantitative determinations of such efficiencies are extremely difficult. Particles 1 micron and less in size weigh practically nothing, yet, according to recent investigations, they are held most tenaciously in the lungs.[3]

Fortunately, two new methods, developed in connection with gas-mask research during the war, are now available for determining the efficiencies of filters for very fine particles in air—electrical precipitation of the suspended particles on a tube of very thin aluminum

[1] Lanza, A. J., and Higgins, Edwin, Pulmonary disease among the miners in the Joplin District, Missouri, a preliminary report: Tech. Paper 105, Bureau of Mines, 1915, pp. 22–32.

[2] Higgins, Edwin, Lanza, A. J., Laney, F. B., and Rice, George S., Siliceous dust in relation to pulmonary disease among miners in the Joplin district, Missouri: Bull. 132, Bureau of Mines, 1917, pp. 22–24.

[3] Final Report of the Miners' Phthisis Prevention Committee, Union of South Africa: January 10, 1919, 110 pp.

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foil,[4] and optical comparison of the Tyndall effect, using tobacco smoke and other suspensions.[5]

This report covers an application of these methods to a comprehensive study of sugar-tube filters, with especial reference to size of tube, depth of sugar, size of granules of sugar, and effect of moisture.

SUGAR TUBES USED BY PREVIOUS INVESTIGATORS.

NEW YORK SUBWAY SUGAR TUBE.

Figure 1 shows the design of a tube used in a study of dust conditions in the New York subway from 1905 to 1907.[6] Fifty cubic feet of air are drawn through 2 inches (about 20 grams) of finely granulated sugar in a glass tube 1 inch in diameter, supported by a plug of wire gauze. Suction is produced by a small portable Root's blower and the volume of air measured with a gas meter. In the laboratory the sugar is dissolved in distilled water, filtered through a Gooch crucible, washed, dried at 100° C., and weighed. From the increase in the weight of the crucible the milligrams of dust per cubic meter of air are calculated.

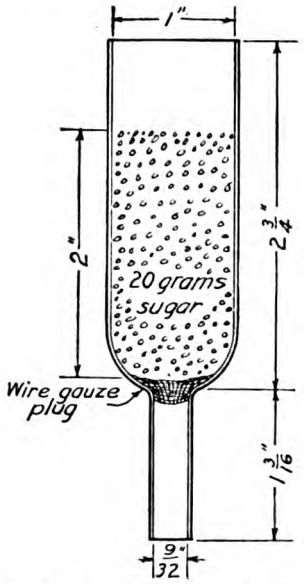

FIGURE 1.—Sugar tube of design used for the study of dust in the New York subway.

SOUTH AFRICAN SUGAR TUBE.

The Miners' Phthisis Prevention Committee of the Union of South Africa has made an extended study of dust measurement in siliceous mines.[7] The committee began its work in 1912 and are still continuing in 1921. During this time thousands of determinations of the weight of dust in air were made with the sugar-tube filter as follows:

Samples of one-third cubic meter or more of air containing dust are aspirated with a calibrated foot pump through 40 grams of granulated sugar, between 12 and 60 mesh in size, supported on a wire gauze or a layer of cotton or cloth in a glass tube which is usually 1½ inches in diameter (fig. 2). Tubes of other dimensions are also used extensively, the diameters varying from 1¼ to 2½ inches. In

[4] Tolman, R. C., Ryerson, L. H., Brooks, N. P., and Smyth, H. D., An electrical precipitator for analyzing smokes: Jour. Am. Chem. Soc., vol. 41, 1919, pp. 587-589.

[5] Fieldner, A. C., Oberfell, A. G., Teague, M. C., and Lawrence, J. N., Methods of testing gas masks and absorbents: Jour. Ind. and Eng. Chem., vol. 11, 1919, pp. 519-540.

[6] Soper, G. A., The air and ventilation of subways: New York, 1908, p. 244.

[7] General Report of the Miners' Phthisis Prevention Committee, Union of South Africa: Mar. 15, 1916, 199 pp.; Final report of the Miners' Phthisis Prevention Committee, Union of South Africa: Jan., 10. 1919, 110 pp.

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the narrow tubes resistance is reduced by using coarse granulated sugar in a 3-inch layer; in the wide 2½-inch tube, fine sugar in a 1½-inch layer is used, the total weight being kept approximately the same for the different sizes of tubes.

At the laboratory the sugar is dissolved in water and filtered through a screen of 260 meshes to the inch, which removes all particles larger than 50 microns in diameter. The solution containing the particles under 50 microns is then divided by a sedimentation

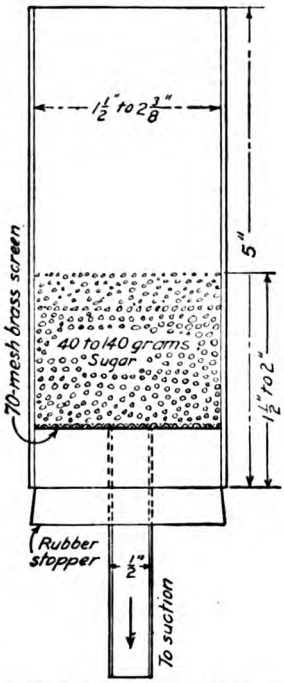

FIGURE 2.—Sugar tube of South African design, used in experiments by the Bureau of Mines.

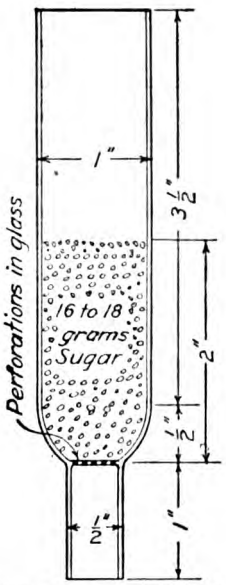

FIGURE 3.—Type A sugar tube used in earlier investigations of dust in air by the Bureau of Mines.

process and division of the solution into two parts, containing, respectively, "fine" dust, above 12 microns in diameter, and "very fine" dust, below 12 microns in diameter. The solutions are filtered through filter paper, washed, the paper ignited, and the residue weighed. Deductions are made for a corresponding blank and the weight of dust of each size in milligrams per cubic meter of air calculated.

BUREAU OF MINES TYPE A SUGAR TUBE.

The design of the sugar tube used in early investigations [8] of the Bureau of Mines is shown in detail in figure 3. The perforated glass

[8] Higgins, Edwin, Lanza, A. J., Laney, F. B., and Rice, George S., Siliceous dust in relation to pulmonary disease among miners in the Joplin district, Missouri: Bureau of Mines, Bull. 132, 1917, p. 116.

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plate supporting a 1½ to 2 inch layer of unsized granulated sugar is fused to the walls of the tube. Thirty-five to one hundred liters of dusty air are aspirated through the tube by the lungs of the sampler, who uses a mouthpiece equipped with tubes and valves; the exhaled air is measured in a bag of 35 liters capacity. In the laboratory the sugar with included dust is dissolved in water, the solution filtered through a Gooch crucible, and the insoluble residue washed, ignited, and weighed. Results are computed to milligrams of dust per 100 liters of air.

FACTORS GOVERNING THE DESIGN OF SUGAR TUBES.

MATERIAL OF TUBE.

The material from which a sugar tube is made should be cheap, easily fashioned into the desired shape, resistant to erosion from the sugar particles, resistant to corrosion from moisture, powder smoke, and other fumes, and not easily broken by ordinary handling or in transmitting to the laboratory.

Glass tubes are cheap and resist erosion and corrosion; moreover, they can be cleaned easily and the chances of adding particles from the tubes are negligible. They have the disadvantage of being fragile and are not readily fitted with the screens needed to confine pulverized sugar.

Metal, on the other hand, is not fragile and can be so made that the screens are soldered to the tube, thus preventing the fine sugar from passing around the edges of the screen while the tube is being mailed from the laboratory to the mine. Tests of aluminum, brass, copper, nickel, and monel metal in contact with wet sugar for three weeks showed that monel metal and nickel do not corrode sufficiently to add any appreciable number of insoluble particles to the sugar solution. The other metals showed corrosion. However, metal tubes made from monel or nickel cost approximately 6 to 10 times as much as glass. Therefore, all things considered, a glass tube with a monel metal screen is to be preferred. The ends are closed with cork stoppers, which are much cheaper than rubber and equally suitable.

SHAPE OF TUBE.

The simplest form of tube is a straight cylinder with a one-hole stopper at the bottom, similar to the South African design shown in figure 2 (see p. 5). Such tubes have proved satisfactory, but because of greater resistance to the flow of air and the unused sugar in the corners, it is better to draw out the lower end as shown in figures 1, 3, or 4 (see pp. 4, 5, and 8).

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QUANTITY OF SUGAR.

It is desirable to keep the quantity of sugar charged in a tube as small as possible, consistent with high dust filtering efficiency, as thereby the error due to impurities in the sugar is kept small and the time of dissolving the sugar and filtering the solution is reduced to a minimum. One hundred grams of sugar is the largest amount that can be handled conveniently in the laboratory. This amount has been used regularly in the bureau's work with type B tubes, figure 4 (see p. 8), and 14 to 65 mesh granulated sugar; with powdered sugar, 48 to 150 mesh, the amount can be reduced to 50 or 60 grams.

DIAMETER OF TUBE.

Sugar tubes varying from ¾ inch to 2½ inches in diameter have been used by various investigators. With a constant depth of sugar the efficiency of the tube increases and the pressure drop decreases as the diameter is enlarged. Large tubes are therefore preferable in giving a maximum filtering efficiency with a minimum resistance to flow. The larger tubes require more sugar, this factor imposing an upper practicable limit at about 2½ inches diameter.

DEPTH OF SUGAR LAYER.

With ordinary granulated sugar the efficiency increases with the depth of the layer up to 3 inches, but beyond this there is little gain in efficiency; the very fine particles seem to be carried through the comparatively large interstices of the sugar layer. On the other hand, the increase of resistance to flow is directly proportional to the depth of the layer. The depth of the layer should therefore not exceed the minimum needed for obtaining the high efficiency for a given size of sugar particle. In the experiments with 14 to 65 mesh sugar, increasing the depth beyond 3 inches did not result in further increase of efficiency. Finer granules give a better alternative. When powdered sugar of 48 to 150 or even 200 mesh was used, it was possible to get practically complete removal of the finest dust in relatively thin layers from ½ to 1 inch.

SIZE OF SUGAR GRANULES.

Granulated sugar varying from 12 to 60 mesh has been used by most investigators. This size is easily obtained and prepared for use. However, as will be shown in the subsequent experiments, very fine dust particles of the size of tobacco smoke can not be caught to any great extent in tubes which have no sugar finer than 60. To remove these fine smoke particles requires a layer of from ½ to 1 inch of powdered sugar ranging from 48 to 150 or 200 mesh. Sugar of this degree of fineness produces a high resistance to flow—from 2 to

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4 inches of mercury—which necessitates a well-designed reciprocating pump or positive rotary suction pump to aspirate the air. It is an unsettled question in the minds of the authors whether or not this extremely high degree of efficiency of removal of fine dust particles of the order of tobacco smoke is necessary or even desirable in the investigation of dusty atmospheres. As will be shown later, these very fine particles have practically negligible weight and most of them are too small to be seen and counted under the microscope as used. Obviously, if they are neither weighed nor counted, there is no need of catching them in the sugar tube.

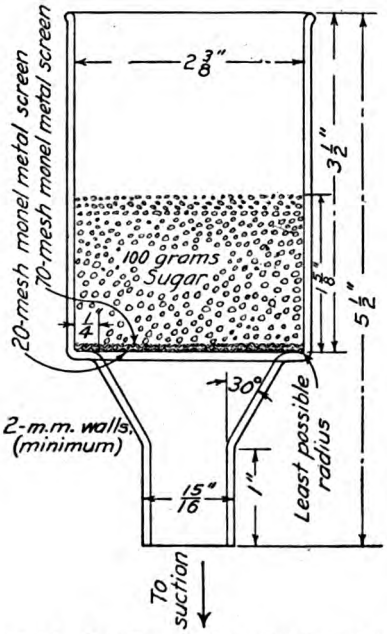

FIGURE 4.—Type B sugar tube used at present by the Bureau of Mines for collecting dust samples.

This investigation was therefore carried out with two general sizes of sugar—granulated sugar of various sizes from 14 to 65 mesh in tubes which gave a low pressure-drop at 32 liters per minute, not exceeding 12 inches of water; and powdered sugar of various sizes ranging from 48 to 200 mesh, in which the pressure-drop ranges from 1 to 4 inches of mercury.

The best design of low-resistance or granulated-sugar tubes showed weight efficiencies with silica dust of 70 to 90 per cent, and optical efficiencies against very fine particles, such as tobacco smoke, of 40 to 60 per cent.

The best design of high-resistance or pulverized-sugar tubes showed optical efficiencies against tobacco smoke of 90 to 100 per cent. These tubes were $2\frac{3}{8}$ inches in diameter and contained 75 grams of powdered sugar of 48 to 150 mesh in a 1-inch layer, giving a resistance of 2 to 3 inches of mercury.

BUREAU OF MINES TYPE B SUGAR TUBE, LOW RESISTANCE.

Figure 4 gives the details of the low-resistance sugar tube, known as type B, adopted for dust investigations in western metal mines in 1919–1920 by the Bureau of Mines and the U. S. Public Health Service. The glass tubes are blown in a mold; they are $2\frac{3}{8}$ inches interior diameter, and have restrictions perpendicular to the walls for supporting the screens; from there the walls taper to a tube $\frac{15}{16}$ inch in outside diameter. The screens which support the sugar are of monel metal

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wire, which is noncorrosive. The lower screen is made of wire sufficiently stiff to support the sugar without sagging. Over the heavier screen is a lighter one, with 70 meshes to the inch, for retaining the sugar. Both screens are cut of slightly larger diameter than the glass tube, so that they stay in place after being put into position. One hundred grams of sugar is used, passed through a screen of 14 meshes to the inch, and retained on one of 65 meshes to the inch. This fills the tube to a depth of about 1⅝ inches. The principal advantage of this sugar tube over the other forms is its lesser resistance to the flow of air and greater filtering efficiency due to the large cross section of filtering medium. The resistance of various types of tubes is given in Table 1.

TABLE 1.—*Resistance to flow of air through different sugar tubes.*

[Sugar, 14 to 65 mesh.]

Type of tube.	Diameter of tube.	Rate of flow of air.	Resistance to flow of air (inches of water column).						
			Empty tube.	40 grams of sugar in tube.		100 grams of sugar in tube.		1⅜ inches depth of sugar.	
				Loose.	Compact.	Loose.	Compact.	Loose.	Compact.
	Inches.	*Liters per min.*							
Bureau of Mines, A type	⅞	32	10	.....	.....	.....	.....	70	[a]>95
Do.....	⅞	29	10	.....	.....	.....	.....	58	95
South Africa.....	¾	32	½	.....	.....	.....	65	.....	[a]>95
Do.....	¾	29	½	.....	.....	.....	55	.....	95
Do.....	1½	32	⅜	11⅜	13⅜	.....	.....	11⅜	13⅜
Do.....	2⅜	32	⅜	2	2	6	7	6	10
Bureau of Mines, B type	2⅜	32	⅛	2	2	3	5½	3½	6½

[a] 32 liters per minute above capacity of testing apparatus.

This resistance and consequently the filtering efficiency of a given tube varies with the manner of packing the sugar in the tube. A tube loosely filled with 14 to 65 mesh granulated sugar contains 0.804 to 0.862 gram per c. c. of calculated tube volume. The average is 0.832 gram.

In the experimental work described in this report the sugar was settled by tapping the tube on the side until no further settling took place. Under these conditions 1 c. c. of sugar weighed from 0.877 gram to 0.984 gram, averaging 0.916 gram.

METHODS FOR DETERMINING THE FILTERING EFFICIENCIES OF SUGAR TUBES.

Sugar tubes were tested for filtering efficiencies by two methods. In the first or optical method a suspension of tobacco smoke or silica dust in air was passed through the filter. Smoke taken from

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points before and after it had passed through the filter was directed in small streams from nozzles of equal diameter into a beam of bright light in a dark box. Visual comparison of the two streams was made. When the unfiltered smoke was diluted with a measured quantity of pure air until it matched the filtered smoke in intensity of reflected light, a means of quantitatively determining the measure of the efficiency of a filter was obtained. This method was developed in the Chemical Warfare Service,[9] but the apparatus used in experiments described in this paper had some modifications.

In addition to the testing against tobacco smoke, similar tests were made against silica dust by creating a cloud of dust in the air, passing it through the apparatus, and measuring it by the method of optical comparison.

The second or weighing method of testing involved weighing a quantity of silica dust in a small apparatus in which a cloud of the dust was generated, passing the air with its suspended dust through a sugar filter, dissolving the sugar, filtering off the dust, washing, igniting, and weighing the silica obtained, and comparing this with the loss in weight of silica from the dust-cloud producer. In other tests by this method a small Cottrell electrical precipitator was used to catch the silica dust passing through the filter, and the dust so caught was weighed.

OPTICAL TEST METHOD.

DESCRIPTION OF APPARATUS FOR OPTICAL METHOD.

TOBACCO SMOKE AS A TESTING MEDIUM.

Figure 5 is a diagram and Plate I a photograph of the apparatus for testing sugar tubes by tobacco smoke. Air under pressure is furnished by a small motor-driven rotary blower. The pressure is maintained at 4 inches of mercury by regulating a screw clamp on the outlet end of the apparatus. This pressure, which is sufficient to force air through the entire apparatus against the resistance of the sugar tube and other parts, is measured by a mercury manometer near the pump. Next to the manometer, in the direction of the flow of air, is a flow meter which measures the rate of flow of air. Thirty-two liters per minute are used in this work, regulation of the rate being obtained by the valves on the pipes near the pump. After it leaves the flow meter, the air passes through the 2-inch iron pipes, arranged six in parallel, which constitute the tobacco burners.

[9] Fieldner, A. C., Oberfell, G. A., Teague, M. C., and Lawrence, J. N., Methods of testing gas masks and absorbents: Jour. Ind. Eng. Chem., vol. 11, 1919, pp. 519–40.

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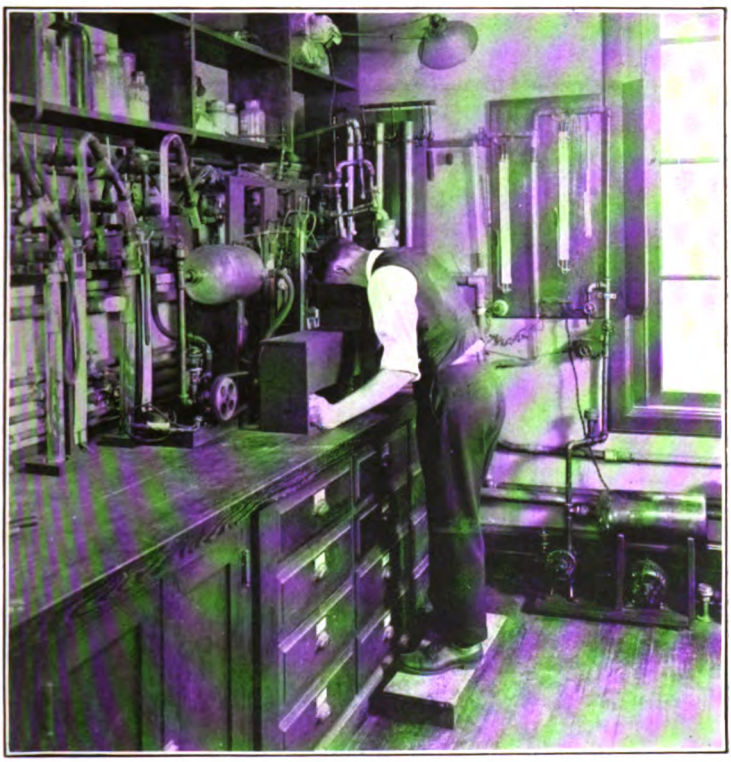

APPARATUS FOR TESTING FILTERS WITH TOBACCO SMOKE.

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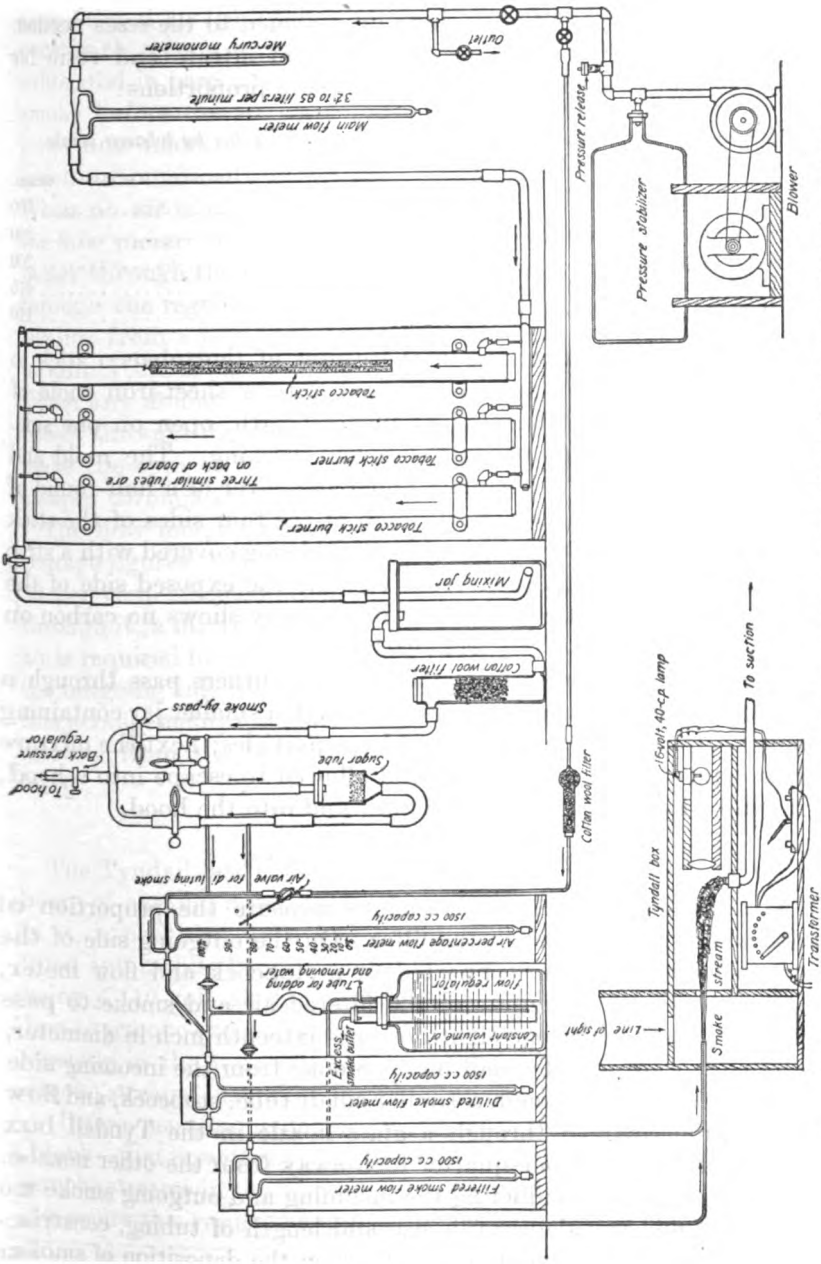

FIGURE 5.—Apparatus arranged for testing sugar tubes against tobacco smoke with optical measurements of filtering efficiency.

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PREPARATION OF TOBACCO FOR BURNERS.

The tobacco used is molded into sticks by the following formula: Sun-dried tobacco leaf is ground and screened to the sizes needed. The sized material is mixed with potassium nitrate and rosin for binder, as well as smoke production, in these proportions:

Formula for tobacco sticks to be used in testing sugar tubes by tobacco smoke.

Tobacco:	Grams.
20 to 48 mesh	500
48 to 65 mesh	300
65 to 100 mesh	200
Rosin, through 100-mesh	475
Potassium nitrate, through 65-mesh	110

A candle wick is imbedded in the center of the tobacco stick to add strength, and the mixture pressed into a sheet-iron mold of 1-inch-square cross section and 15 inches length, open on one side. The mold is lined with paper to prevent sticking. The mold and mixture are baked on a hot plate under the cover of a half-round of sheet iron 3 inches in diameter. Each of the four sides of the stick in turn is baked to a brown color, the mold being covered with a strip of sheet metal before it is inverted to bake the exposed side of the stick. Smoke from sticks prepared in this way shows no carbon on the filter and the ash is free from carbon.

The air and the smoke from the tobacco burners pass through a large jar, where they are mixed, then through a smaller jar containing a wad of cotton wool for filtering out large particles; next the mixture is passed through the sugar filter and allowed to escape into a hood, or it can be by-passed around the filter and into the hood.

MEASUREMENT OF TOBACCO SMOKE.

The remaining apparatus is used to measure the proportion of smoke which passes through the filter. On the outgoing side of the filter a small glass tube, connected to a stopcock and flow meter, allows 1,500 c. c. per minute of the filtered air and smoke to pass through a glass nozzle, one-eighth or one-sixteenth inch in diameter, into a light beam in a Tyndall box. Smoke from the incoming side of the filter is drawn through a similar small tube, stopcock, and flow meter, and discharged through a glass nozzle in the Tyndall box placed parallel to and one-quarter inch away from the other nozzle. The two systems for conducting the incoming and outgoing smoke to the Tyndall box are identical in size and length of tubing, constrictions, and bends, to have an equal effect on the deposition of smoke particles on the walls.

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MATCHING SMOKE STREAMS.

In order to dilute the incoming smoke to match the outgoing smoke, pure filtered air from the pump is passed through a controlling stopcock with a long lever arm for fine adjustments and a flow meter calibrated in percentage figures. It is then mixed with the incoming smoke before the smoke comes to its 1,500-c. c. flow meter. This latter flow meter is equipped with the device of Oberfell and Mase,[10] which automatically maintains a constant flow of 1,500 c. c. of gas. When no air is added, 1,500 c. c. of undiluted smoke passes through the flow meter; when 1,500 c. c. of air is admitted to the line, only air passes through the flow meter and the smoke passes out of the system through the regulator and escapes into the room. The smoke leaves the line from a point behind that at which the pure air enters, hence no admixture of smoke and air occurs before the excess smoke escapes. When any amount of the pure air less than 1,500 c. c. is admitted, it passes through the flow meter with the amount of smoke required to make the sum of 1,500 c. c., and the residual smoke automatically escapes through the regulator.

The flow meter which measures the pure air is calibrated in percentage figures, 1,500 c. c. being 100 per cent. Thus, when a filter is 50 per cent efficient or allows half of the incoming smoke to pass through it, a mixture of 50 per cent of smoke and 50 per cent of pure air is required in the Tyndall box to match the stream of smoke from the outgoing side of the filter. After smoke streams are matched by this arrangement, the percentages of efficiencies of the filters are read directly from the water column in the percentage-calibrated flow meter.

DESCRIPTION OF THE TYNDALL BOX.

The Tyndall box is made of wood painted dead black inside. The beam of parallel light, opposite in direction to the streams of smoke in it, is provided by a lens and 40-candlepower, 16-volt, nitrogen-filled automobile lamp. Voltage is regulated by a small transformer using a 110-volt alternating current. Suction is maintained on the box to remove excess smoke. The line of sight passes through a small opening in the box, allowing observation of about 3 inches of the smoke streams just after they had passed from the nozzles.

Before measurements are made with the apparatus it is tested blank—that is, with an open tube in the place of the sugar tube. The smoke streams in the Tyndall box are required to match, but in order to secure this result the apparatus needs frequent cleaning.

[10] Oberfell, G. A., and Mase, R. P., An automatic compensating flow meter: Jour. Ind. Eng. Chem., vol. 11, 1919, pp. 294–296.

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SILICA DUST AS A TESTING MEDIUM.

The apparatus for determining, by optical means, efficiencies of sugar in filtering silica dust suspended in air is the same as that used for tobacco smoke except for the tobacco burner. The latter is replaced by an apparatus for creating a cloud of the dust in the air. The dust-cloud producer is shown in figure 6. It consists of a wide glass tube, 2½ inches in diameter, tapered at the bottom over a length of 6 inches to ½ inch in diameter. The narrow tube is bent into a U to retain the dust. At the top of the glass tube is a rubber stopper with one hole, through which a glass T passes. One arm of the T is connected with the filtering apparatus and the other is provided with a rubber tube and clamp, through which dust can escape. About half a pound of silica dust is heated from 200 to 300° C. before being put into the apparatus, and the air to be used is dried with calcium chloride, as a small amount of moisture prevents the formation of good clouds. The air with its suspended silica dust is filtered through the wad of cotton wool before it passes to the sugar filters, only the smaller dust particles taking part in the experiments.

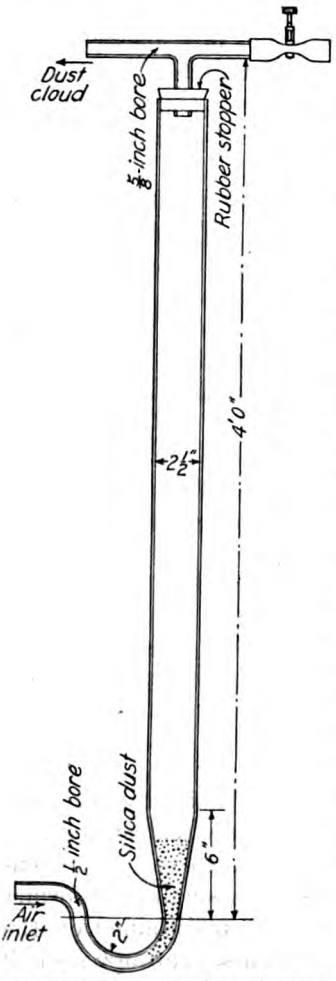

FIGURE 6.—Apparatus for producing a cloud of silica dust in air.

When this apparatus is in use, silica dust is precipitated throughout it gradually, but at a rate much more rapid than that of tobacco smoke. Cleaning is needed more often, and greater care is given to maintain Tyndall beams of equal intensities, when the apparatus is tested with blank filters.

SIZE OF SMOKE AND SILICA PARTICLES USED FOR TESTING.

Wells and Gerke [11] have shown that the particles of tobacco smoke measure .273 micron in diameter on the average, with an average deviation of 1.8 per cent. The tobacco smoke utilized by Wells and Gerke for these measurements is produced in the same way as that

[11] Wells, P. V., and Gerke, R. H., An oscillation method for measuring the size of ultramicroscopic particles: Jour. Am. Chem. Soc., vol. 41, 1919, pp. 312–29.

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described in this paper. Since tobacco-smoke particles are so small and uniform in size and have very little tendency to clog a filter, they make an excellent medium with which to test efficiency with respect to very fine particles.

The silica dust referred to in these experiments was ground flint, such as is used in making glazes for ceramic ware. Eighty-eight per cent passed through a screen of 200 meshes to the inch and ranged from that size to ultramicroscopic sizes; hence, there was no uniformity of size in the silica particles. Only the smaller particles of silica dust were used, however, as the suspension was filtered through a wad of cotton batting in the optical testing machine. The particles were undoubtedly larger than those of tobacco smoke.

PROCEDURE IN MAKING OPTICAL MEASUREMENTS.

Before a filter was tested against either smoke or silica dust, the empty tube was tested for resistence to flow of air. A flow of 32 liters per minute was standard. The required amount of sugar was then added and packed to apparently average density by tapping the sides of the tube, and the resistance to flow again determined in inches height of water or mercury column. The difference between the second and the first determinations was resistance due to sugar.

After measurements of resistance—made on a separate apparatus—the sugar tube was placed in position and was ready for measurements of efficiency. Experience has shown that a thin smoke serves better for making optical comparisons when efficiency of filtering is low, as is the case of sugar, so that only one tobacco stick is burned. When filtering efficiencies are high (95 per cent or more) denser smokes are better. Six tobacco sticks are burned when measurements of very high efficiencies are to be made. The actual filtering efficiency of the sugar is independent of the concentration of tobacco smoke or silica dust. This efficiency increases with denser clouds, as the deposited dust decreases the size of the voids between the sugar grains.

The accuracy of determinations decreased with the decrease in the efficiency of sugar tubes. With efficiencies of 98 per cent, measurements could be checked to less than 1 per cent; but when efficiencies ranged at 25 per cent or lower, errors of individual determinations were as high as 15 per cent.

There was also a slight tendency for sugar filters to increase in efficiency against smoke with use. This was probably due more to the packing of the sugar because of its wetting from the water-saturated smoke than from a clogging effect of the smoke itself.

With silica dust there was a marked clogging effect with continuous increase in filtering efficiency for each sugar tube. Moreover, there

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was a continuous decrease in the density of the cloud of silica dust with use, probably due to the decrease in the number of fine particles of dust in the cloud producer. The decrease in cloud density and consequent lowering of the clogging effect from a given batch of silica in the cloud producer causes tests of efficiency of the same kind of sugar tubes to show consecutively lower efficiencies. The cotton filter was observed to clog with use, but renewing it did not noticeably increase the cloud density.

Because of the difficulty of accurate readings with low efficiencies of filtration and other disturbing effects, a number of observations of efficiencies were always made. In general, the following procedure was observed with tobacco smoke: First, a reading was secured which was known to be greater than the actual efficiency by an amount just perceptible in the Tyndall streams; then a reading, lower in efficiency than the actual, was secured in the same way. One man made six such alternate observations and the process was then repeated by a second man. Table 2 illustrates some typical results secured in this way.

TABLE 2.—*Typical observations made in determining efficiencies of sugar tubes against tobacco smoke.*

[Smoke from one stick of tobacco; rate of flow, 32 liters per minute; tube, 2⅜ inches inside diameter; sugar, 14 to 65 mesh.]

Depth of sugar (inches)	2	3
Resistance to flow of air (inches water):		
Empty tube	⅛	⅛
Tube with sugar before test	7½	10¼
Tube with sugar after test	10⅜	11½

Readings of efficiency by operator 1, per cent			Readings of efficiency by operator 2, per cent		
	40	35		35	45
	15	24		21	25
	40	65		37	47
	20	25		22	25
	40	70		38	45
	17	35		25	23
Total	172	254	Total	178	210
Maximum	40	70	Maximum	38	47
Average	29	42	Average	30	35
Minimum	15	24	Minimum	21	23

Final maximum	40	70
Average of readings by operators 1 and 2	30	38
Final minimum	15	23

In the tables that follow, generally only the maximum, minimum, and average of the observations are reported.

When two sugar tubes were being compared against silica dust, as, for example, one tube with dry sugar and one with moistened sugar, series of readings were made alternately on a fresh, dry tube over a period of three minutes, then on a moistened tube over a like period, then on a fresh dry tube, and so on. The individual observa-

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tions in these cases were the result of attempts to secure matched light reflections from the two dust streams in the Tyndall box. The time of each observation after a sugar tube was first used was recorded. For interpolations, when necessary, efficiencies were plotted against time and the efficiencies for the desired times taken from the curves. The comparative results from the first, third, and fifth, or dry sugars were then averaged and compared with the like averages from the second and fourth tests, which were on wet sugars. Likewise, results from the second, fourth, and sixth tests were averaged and compared with those from the third and fifth tests. This process gave two sets of figures for each pair of sugar tubes undergoing comparison, from which conclusions could be drawn. More minute details of procedure and methods will be described in connection with the results themselves.

RESULTS OF OPTICAL TESTS ON LOW RESISTANCE SUGAR TUBES.

EFFECT OF DIAMETER OF SUGAR TUBE.

Table 3 gives the results of optical tests with tobacco smoke for determining the effect of the diameter of the tube on the filtering efficiency.

TABLE 3.—*Results of experiments showing the effects of varying diameters on the efficiency of sugar tubes.*

[Tobacco smoke from one stick; rate of flow, 32 liters per minute; depth of sugar, 1¾ inches.]

Diameter of tube.	Size of sugar.	Efficiency of filter.
Inches.	*Mesh per inch.*	*Average per cent.*
1½	20 to 35	23
2⅛	20 to 35	27
1½	35 to 48	24
2⅛	35 to 48	32
1½	48 to 65	36
2⅛	48 to 65	60
1½	14 to 65	38
2⅛	14 to 65	54

The results show an increase in efficiency as the diameters of the tubes increase. For tubes of 1½-inch diameter as compared with those of 2⅛-inch diameter, the smallest difference is 4 per cent and the largest 24 per cent, with an average of 13 per cent in favor of the wider tube.

EFFECT OF DEPTH OF SUGAR LAYER.

Table 4 gives the results of experiments arranged to show the effect of the depth of the sugar layer on the efficiency of sugar tubes.

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TABLE 4.—*Results of experiments arranged to show the effects of the depth of sugar on efficiencies of sugar tubes.*

[Material used for tests, tobacco smoke from one stick; rate of flow, 32 liters per minute; Bureau of Mines tube, design B, 2⅜ inches diameter; size of sugar, 14 to 65 mesh.]

Depth of sugar.	Resistance to flow of air.			Efficiency of sugar tube.
	Empty tube.	Tube with sugar.		
		Before test.	After test.	
Inches.	*Inches of water column.*	*Inches of water column.*	*Inches of water column.*	*Average per cent.*
1	⅛	3⅛	3½	14
2	⅛	7½	10⅜	30
3	⅛	10⅛	11½	38
4	⅛	Over 12	Over 12	38

To a depth of 3 inches, the results show an increase in efficiency somewhat proportional to the depth of the sugar. There is no advantage in going beyond this depth. The voids with 14 to 65 mesh sugar allow the very fine particles to pass through, even at a considerable depth of layer.

EFFECT OF THE SIZE OF SUGAR GRANULES.

Sugar was graded in size by screening through Tyler standard screens. The openings in the screens were of these sizes:

Sizes of openings in screens of different mesh.

Meshes to the inch.	Diameter of opening. *Inch.*	Meshes to the inch.	Diameter of opening. *Inch.*
14	0.046	65	.0082
20	.0328	100	.0058
35	.0164	150	.0041
48	.0116	200	.0029

With these screens six sizes of granulated sugar were made:

1. Through 14-mesh and on 20-mesh screens.
2. Through 20-mesh and on 35-mesh screens.
3. Through 35-mesh and on 48-mesh screens.
4. Through 48-mesh and on 65-mesh screens.
5. Through 65-mesh and on 100-mesh screens.
6. Through 14-mesh and on 65-mesh screens.

The last contained nearly all the sugar as received unsized. A screen analysis of high-grade, commercial granulated sugar made by the Franklin Sugar Refining Co., of Philadelphia, Pa., and packed in paper cartons at the mill, gave the following results when tested for size:

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TABLE 5.—*Screen analysis of granulated sugar.*

	Per cent.
On 10-mesh screen	0.2
Through 10-mesh on 14-mesh screen	2.6
Through 14-mesh on 20-mesh screen	14.7
Through 20-mesh on 35-mesh screen	56.2
Through 35-mesh on 48-mesh screen	14.1
Through 48-mesh on 65-mesh screen	7.2
Through 65-mesh on 100-mesh screen	4.4
Through 100-mesh on 200-mesh screen	.5
Through 200-mesh screen	.1
Total	100.0

Most of the granulated sugar used during these experiments, whether bulk sugar from barrels or package sugar packed at the mills, was of approximately the same size; nearly all of it passed a screen of 14 meshes to the inch and lodged on a screen of 65 meshes to the inch. This is practically equal to the standard size of 12 to 60 mesh of the South African committee.

Tobacco smoke was used as a medium for testing. Table 6 gives the results of experiments to show the effect of the size of sugar granules on filtering efficiency.

TABLE 6.—*Results of experiments arranged to show the effect of the size of granules on efficiencies of sugar tubes.*

[Material used for test, tobacco smoke from one stick; rate of flow, 32 liters per minute; tubes, Bureau of Mines type B, 2½-inch diameter; depth of sugar, 1¼ inches.]

Size of sugar.	Efficiency of filter.		
	Maximum.	Average.	Minimum.
Meshes per inch.	*Per cent.*	*Per cent.*	*Per cent.*
20 to 35	49	27	5
35 to 48	46	32	15
48 to 65	72	60	50
14 to 65	64	54	42

The results show an increased efficiency with decrease in the size of the sugar granules. The 14 to 65 mesh sugar showed efficiencies averaging between the 35 to 48 and the 48 to 65 mesh sizes. Among the low-resistance sugars 14 to 65 mesh seems best adapted for general use, from the standpoint of convenience and efficiency.

EFFECT OF WETTING SUGAR WITH WATER OR ALCOHOL.

When tests were made with tobacco smoke, dry sugar was always used at the start, but the smoke contained so much moisture produced by the burning of the tobacco, which either condensed on the sugar or was caught by it, that the sugar quickly became moist. After the smoke had passed through the sugar tube for from one to two minutes, the moisture was usually sufficient to prevent the sugar

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from falling from the tube when it was inverted. As previously stated, the moisture in the smoke causes some packing of the sugar when the latter becomes damp. This was largely responsible for the slight increase in the efficiency of sugar tubes with use against tobacco smoke and for the increase of the resistance to the flow. Because of the moisture in the smoke itself, all of the tests with tobacco smoke may be considered as performed with damp sugar tubes.

To secure a comparison of dry sugar and wet sugar, tests were made against silica dust clouds. After the sugar had been placed in the tube it was dampened with distilled water or 35 per cent alcohol from a continuous-spray medicine atomizer while air was being drawn through at a rate of 32 liters per minute. The air current drew the moisture into the lower layers of sugar, but most of it was retained near the surface. The spraying was continued until the surface was visibly wet. The 35 per cent alcohol was used since it had been recommended by the South African committee [12] for increasing the efficiency of tubes when used in dry atmospheres.

Dropping water on the sugar was unsatisfactory because of the effect of the water in gathering the sugar granules together in clumps, with crevices between them. The 35 per cent alcohol had a much less clumping effect when dropped on the sugar, but spraying both the water and the alcohol gave better results.

Three series of tests were made with three fresh charges of silica in the dust-cloud producers. The first series consisted of three tests of three minutes duration each with dry filters and three tests of three minutes duration each with water-wet filters. The wet and the dry filters were alternated, the wet filter being used first. The second series was like the first, except that a dry filter was used first. In the third series, 35 per cent alcohol was used to wet the sugar. Table 7 gives the results of the tests.

Comparison of the averages of the percentage efficiencies for the wet and dry sugars in Table 7 shows that the wet sugar was slightly more efficient than the dry for filtering silica dust from air. The average difference of efficiency for all the observations on water-wet sugar amounted to only about 4 per cent in favor of the wet sugar; the 35 per cent alcohol-wet sugar gave an average for all observations about 5 per cent higher than the corresponding observations on dry sugar. Hence, no material advantage is gained in wetting the sugar with either alcohol or water.

[12] General Report of the Miners' Phthisis Prevention Committee, Union of South Africa: Mar. 15, 1916, p. 74.

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TABLE 7.—*Results of experiments to show the effects of moisture on the efficiency of sugar tubes.*

[**Material used for tests, silica dust**; rate of flow, 32 liters per minute; tubes, Bureau of Mines type B, 2⅜ inches diameter; size of sugar, 14 to 65 mesh; weight of sugar per test 100 grams; depth of sugar, 1⅜ inches.]

FIRST SERIES.—SUGAR WET WITH DISTILLED WATER.

Test number.	Condition of sugar.	Resistance to flow of air in inches water column.			Efficiencies.										
		Empty tube.	Tube with sugar.		In 15 seconds.	In 20 seconds.	In 25 seconds.	In 30 seconds.	In 40 seconds.	In 50 seconds.	In 1 minute.	In 1½ minutes.	In 2 minutes.	In 2½ minutes.	In 3 minutes.
			Before test.	After test.											
					Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Wet	⅛	3⅞	10	.....	.....	.....	90	.....	.....	91	96	97	.....	99
2	Dry	⅛	4¼	6	.....	.....	75	.....	80	.....	88	93	94	.....	96
3	Wet	⅛	4	5¼	.....	.....	80	.....	85	.....	89	93	94	.....	94.5
4	Dry	⅛	3⅜	4⅛	.....	72	.....	.....	80	83	84	84	84	.....	80
5	Wet	⅛	4⅛	4½	.....	.....	.....	75	.....	76	77	80	82	.....	84
6	Dry	⅛	3½	3⅝	.....	.....	.....	75	.....	76	76	76	77	.....	78
Average of 1, 3, and 5	Wet	.....	.....	.....	.....	.....	.....	82	.....	.....	86	90	91	.....	93
Average of 2 and 4	Dry	.....	.....	.....	.....	.....	.....	77	.....	.....	86	89	89	.....	88
Average of 3 and 5	Wet	.....	.....	.....	.....	.....	.....	79	.....	.....	83	87	88	.....	89
Average of 2, 4, and 6	Dry	.....	.....	.....	.....	.....	.....	76	.....	.....	83	84	85	.....	85

SECOND SERIES.—SUGAR WET WITH DISTILLED WATER.

1	Dry	⅛	3⅛	6	.....	67	.....	75	.....	.....	81	89	93	95	96
2	Wet	⅛	3⅞	9⅞	.....	.....	.....	91	.....	93	95	97	97	97	97
3	Dry	⅛	3⅛	4½	78	.....	.....	81	.....	.....	86	86	86	87	88
4	Wet	⅛	3½	4¾	81	.....	.....	81	.....	.....	84	86	89	90	91
5	Dry	⅛	3¾	3¾	65	.....	.....	70	.....	.....	74	78	80	82	80
6	Wet	⅛	3½	3¾	63	.....	.....	70	.....	.....	74	74	73	75	78
Average of 1, 3, and 5	Dry	.....	.....	.....	.....	.....	.....	75	.....	.....	80	84	86	88	88

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TABLE 7.—*Results of experiments to show the effects of moisture on the efficiency of sugar tubes*—Continued.

SECOND SERIES.—SUGAR WET WITH DISTILLED WATER—Continued.

Test number.	Condition of sugar.	Resistance to flow of air in inches water column.			Efficiencies.										
		Empty tube.	Tube with sugar.		In 15 seconds.	In 20 seconds.	In 25 seconds.	In 30 seconds.	In 40 seconds.	In 50 seconds.	In 1 minute.	In 1½ minutes.	In 2 minutes.	In 2½ minutes.	In 3 minutes.
			Before test.	After test.											
					Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Average of 2 and 4....	Wet.....	.....	.....	.....	.....	.....	.....	86	.....	.....	90	92	93	94	94
Average of 3 and 5....	Dry.....	.....	.....	.....	.....	.....	.....	76	.....	.....	80	82	83	85	84
Average of 2, 4, and 6.	Wet.....	.....	.....	.....	.....	.....	.....	81	.....	.....	84	86	86	87	89

THIRD SERIES.—SUGAR WET WITH 35 PER CENT ALCOHOL.

1.....	Dry.....	⅛	2¾	3½	.....	76	.....	80	82	84	85	87	90	90	90
2.....	Wet.....	⅛	3	4¼	65	.....	.....	75	.....	80	85	89	91	90	90
3.....	Dry.....	⅛	2½	3	45	.....	.....	60	65	.....	70	80	77	82	87
4.....	Wet.....	⅛	2½	3	52	.....	.....	60	.....	.....	65	74	79	80	80
5.....	Dry.....	⅛	2½	3	.....	.....	.....	53	.....	.....	60	65	67	70	78
6.....	Wet.....	⅛	3	3¾	.....	.....	.....	57	.....	.....	70	77	81	83	85
Average of 1, 3, and 5.	Dry.....	.....	.....	.....	.....	.....	.....	64	.....	.....	72	77	78	81	85
Average of 2 and 4....	Wet.....	.....	.....	.....	.....	.....	.....	68	.....	.....	75	82	85	85	85
Average of 3 and 5....	Dry.....	.....	.....	.....	.....	.....	.....	57	.....	.....	65	73	72	76	83
Average of 2, 4, and 6.	Wet.....	.....	.....	.....	.....	.....	.....	64	.....	.....	73	80	84	84	85

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OPTIMUM LOW RESISTANCE SUGAR TUBE BASED ON OPTICAL TESTS.

The results of the optical tests are not very precise, owing to the impossibility of making close comparisons when the efficiency of the tube is below 80 per cent. However, the relative influence of various factors, including the diameter of tube, depth of sugar layer, size of granules, and wetting of sugar, is shown, and a study of these factors indicates that a sugar tube of the form shown in figure 4 (see p. 8), $2\frac{3}{8}$ inches in diameter, containing 100 grams of 14 to 65 mesh sugar, fairly well packed, is the optimum style of tube where low resistance is necessary, such as when using the breathing bag for taking samples. A tube of this type shows an optical efficiency of from 40 to 65 per cent when tested with tobacco smoke, and of 60 to 80 per cent when tested with silica dust. The resistance of this tube at 32 liters per minute flow is from 2 to 14 inches of water, depending on the degree of packing of the sugar and the proportion of finer particles and moisture present. The increase of efficiency when the sugar is dampened is only 4 to 5 per cent, insufficient to justify moistening it before use.

WEIGHT-TEST METHOD.

Determinations of dust in air are commonly reported in terms of weight and numbers of particles per unit volume of air. The optical tests give a measure of the efficiency of sugar tubes with respect to the number of particles rather than the weight, as the surface-reflecting effect of the very fine particles that tend to pass through the sugar tube is much larger in proportion to the weight than is the reflecting effect of the coarse and heavy particles retained in the tube; therefore, much higher efficiencies would be expected on a weight basis.

DESCRIPTION OF APPARATUS FOR WEIGHT MEASUREMENTS.

The apparatus for determining the efficiencies of sugar tubes by weighing the dust is shown in figure 7. Air from a blower is passed through fused granular calcium chloride to dry it, then through cotton wool and to a flow meter where the rate of flow of 32 liters of air per minute is indicated. After it passes this large flow meter the air is divided into two parts, the smaller passing through a small flow meter which registers rates of a few hundred cubic centimeters per minute, then through the silica dust in the small cloud producer, which is small enough to be weighed on a precision balance. This cloud producer is the same in principle as that used to originate dense dust clouds for the optical determinations, but because its size is small and because only a few milligrams of dust in cloud form are wanted, only a small part of the 32 liters of air is passed through the dust. The T tube at the top of the cloud producer is made a

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part of the producer itself. The main body of the 32 liters of air passes through the arms of the T, mixes with the small volume of air and dust rising from below, and carries it to the sugar tube. The

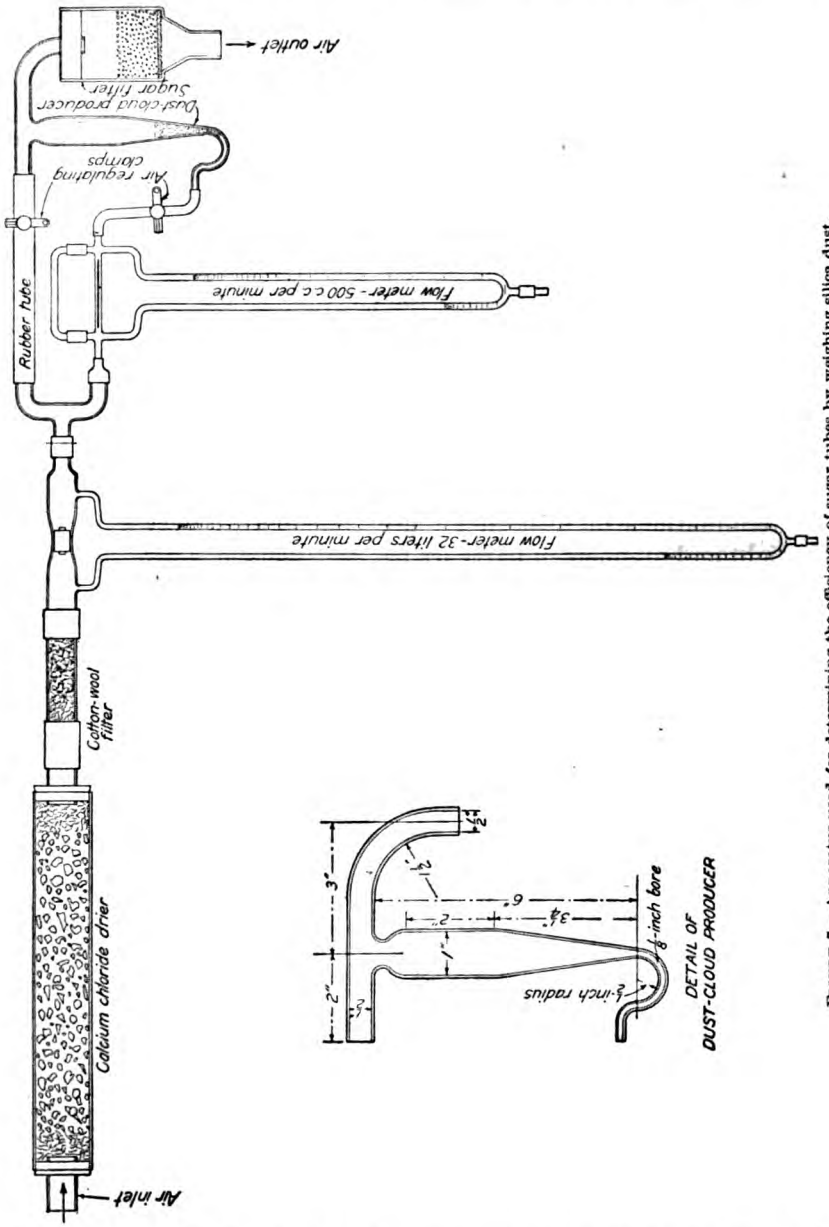

FIGURE 7.—Apparatus used for determining the efficiency of sugar tubes by weighing silica dust.

sugar tube is attached by a rubber stopper to the further arm of the dust-cloud producer, which is curved downward. The air escapes after it passes through the sugar tube. The proportions of air

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passing through the dust and the upper part of the cloud producer are regulated by screw clamps on rubber-tube connections. It is necessary to tap the producer lightly at intervals of about 10 seconds to secure the desired clouds.

PROCEDURE IN MAKING WEIGHING TESTS.

Before the apparatus was assembled for testing, silica dust, freshly dried by heating in a Bunsen flame, was put into the cloud producer and the openings closed with rubber stoppers. The outside was then carefully wiped with a clean cloth and the cloud producer allowed to stand in the balance case for 15 minutes. The balance was of the Ruprecht type used to weigh gases; it had a capacity of 100 grams and was sensitive to 0.01 mg. Weights were recorded to the nearest 0.1 mg. The apparatus was then assembled and operated for 10 minutes; then the dust-cloud producer was removed, stoppered, and weighed with the same precautions used previously. The loss of silica dust constituted the difference in the two weighings.

The sugar with the silica dust caught in it was transferred from the filter tube to a beaker of 1,000 c. c. capacity, the tube carefully washed with distilled water to transfer any remaining dust, and the solution made up to about 600 c. c. The beaker was covered with a watch glass and heated until all soluble matter had dissolved. It was then filtered hot through an 11-cm. ashless filter paper of close texture. When the solutions were handled in this way, about two hours were required for the filtrations, but if they were allowed to stand until cold, more time was needed and mold sometimes formed overnight. To prevent bacterial growth, one c. c. of c. p. formalin was added when necessary. Any residual insoluble matter remaining in the beakers was carefully rubbed from the sides and washed into the filter papers with hot distilled water. Three such washings were given to the beaker and a fourth to the dust in the filter paper. After filtration was completed, the wet filter paper was folded and put point down in a weighed porcelain crucible, the crucible covered, and placed in a cold muffle furnace. The furnace was heated and maintained four hours at red heat, as this was found to be sufficient to burn all combustible matter. The crucible was then cooled in a desiccator over fused calcium chloride. It was weighed on the delicate balance to the nearest milligram. The weight of the crucible had been previously determined, so the gain minus a blank for the sugar represented the silica.

Six determinations as described above were usually run in parallel, two being blanks on the sugar. The method was determined upon after tests had been made on the rate of solution and filtering of sugar on the nonvolatile matter from the sugar and filter paper, and

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on the length of time required for complete ignition. Attempts were made to determine the efficiencies of sugar filters by weighing the sugar tubes directly, but without success. This result was probably due to moisture changes in the sugar during the test and to the unavoidable errors involved in weighing such a large and heavy vessel. Using Gooch crucibles and weighing after drying at 105° C., without ignition, was also investigated and found unsatisfactory, owing to variable amounts of insoluble combustible matter in the sugar.

INSOLUBLE NONCOMBUSTIBLE MATTER IN SUGAR.

Table 8 gives the results of tests to determine the impurities in different brands of sugar which were both insoluble and noncombustible; that is, the blank which must be subtracted from the weight of matter found to obtain the weight of dust.

TABLE 8.—*Insoluble noncombustible matter from different lots of granulated sugar.*

Variety of sugar.	Lot or carton number.	Weight of sugar.	Insoluble noncombustible matter.	Milligrams per 100 grams sugar.
		Grams.	*Mg.*	
Ordinary bulk, from cloth sack	1	140	2.2	1.4
Do	2	140	1.6	1.0
Do	2	140	1.8	1.1
Do	2	140	2.0	1.3
Do	2	140	1.8	1.1
Do	3	140	1.9	1.2
Do	3	140	2.0	1.3
Domino, packed in paper carton	1	140	1.8	1.1
Do	1	140	1.7	1.1
Do	1	140	1.9	1.2
Do	1	140	1.7	1.1
Do	1	140	1.5	.8
Do	1	140	1.6	1.0
Franklin, packed in paper carton	1	140	1.2	.8
Do	1	140	1.4	.9
Do	1	140	1.3	.8
Do	1	140	1.6	1.0
Do	2	100	1.6	1.6
Do	2	100	1.2	1.2
Do	2	100	1.5	1.5
Do	3	100	2.1	2.1
Do	4	100	2.4	2.4
Do	5	100	2.4	2.4
Do	5	100	2.7	2.7
Do	5	100	2.3	2.3
Do	6	100	3.2	3.2
Do	6	100	3.0	3.0

The table shows that ordinary bulk granulated sugar taken from a cloth bag compares favorably with high-grade package sugar in purity. In spite of this fact, bulk sugar is more likely to be contaminated by dust. The greatest difference in the weights of blanks from one lot of sugar, determined by ignition, was 0.4 mg.; however, large differences were found for the several lots, the greatest extremes being 1.2 and 3.2 mg., for different packages of Franklin sugar. These figures include the weight of ash from the ashless filter papers and

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the distilled water, as well as dust from the room air, but such included weights are quite small and constant in comparison with the weights from the sugar itself.

RESULTS OF WEIGHING TESTS ON BUREAU OF MINES TYPE B LOW-RESISTANCE SUGAR TUBE.

The results of the weighing test on the Bureau of Mines type B low-resistance sugar tube are given in Table 9. The sugar solution with the suspended dust was filtered through C. S. & S. blue-ribbon ashless filter papers, ignited and weighed.

Table 9 shows that the weight of silica dust recovered was usually less than that evolved from the cloud producer. The maximum loss of dust was 2.2 mg. and the average loss was 1 mg. Three experiments showed gains of 0.7, 0.1, and 0.1 mg.

TABLE 9.—*Results of weighing tests with silica dust.*

[Sugar, 14 to 65 mesh; Bureau of Mines tube, type B, 2⅜ inches diameter; rate of flow, 32 liters per minute.]

Depth of sugar in tubes.	Weight of sugar.	Dust evolved from cloud producer.	Weight of dust found in sugar tube.	Average blank to be subtracted.	Net weight of dust found.	Dust lost.	Efficiency of dust recovery.	Group No.
Inches.	*Grams.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Per cent.*	
2	125	5.7	8.0	1.5	6.5	[a]0.8	114	1
.....	.....	6.8	7.9	1.5	6.4	.4	94	1
.....	.....	6.5	7.6	1.5	6.1	.4	94	1
.....	.....	.....	1.5	.....	.....	.....	.....	1
.....	.....	8.4	10.2	2.4	7.8	0.6	93	2
.....	.....	8.7	9.7	2.4	7.3	1.4	84	2
.....	.....	4.6	6.8	2.4	4.4	.2	95	2
.....	.....	3.9	6.4	2.4	4.0	[a].1	103	2
.....	.....	7.4	7.6	2.4	5.2	2.2	70	2
.....	.....	.....	2.4	.....	.....	.....	.....	2
1⅛	100	6.8	7.4	2.5	4.9	1.9	72	3
.....	.....	5.6	6.8	2.5	4.3	1.3	78	3
.....	.....	3.8	5.0	2.5	2.5	1.3	66	3
.....	.....	10.2	10.3	2.5	7.8	2.4	77	3
.....	.....	6.4	7.5	2.5	5.0	1.4	78	3
.....	.....	.....	2.4	.....	.....	.....	.....	3
.....	.....	4.0	6.6	2.5	4.1	[a,b]0.1	103	4
.....	.....	6.0	8.0	2.5	5.5	.5	92	4
.....	.....	17.3	19.5	2.5	17.0	.3	93	4
.....	.....	4.6	6.8	2.5	4.3	.3	93	4
.....	.....	.....	2.7	.....	.....	.....	.....	4
.....	.....	.....	2.3	.....	.....	.....	.....	4
.....	.....	6.2	7.9	3.1	4.8	1.4	77	5
.....	.....	6.6	8.3	3.1	5.2	1.4	79	5
.....	.....	4.1	6.7	3.1	3.6	.5	88	5
.....	.....	4.8	7.1	3.1	4.0	.8	83	5
.....	.....	.....	3.2	.....	.....	.....	.....	5
.....	.....	.....	3.0	.....	.....	.....	.....	5

[a] Gain.

[b] Run on a damp day; sugar was damp and caked in the filter.

Experiments with the damp sugar indicated a higher filtering efficiency than those with dry sugar. This result is in accordance with results by optical methods. In general, the weight efficiency of the Bureau of Mines type B tube, with 100 grams of 14 to 65 mesh

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sugar, is from 70 to 90 per cent—from 10 to 15 per cent higher than the optical efficiency with silica dust clouds. The 10 to 30 per cent loss represents fine dust passing through the sugar tube and that caught in the sugar but lost when it passed through the filter paper.

Although C. S. & S. blue-ribbon filter papers of closest texture were used, microscopic examination of the filtrates disclosed numerous particles of fine silica dust.

RESULTS OF TESTS WITH HIGH-RESISTANCE TUBES USING PULVERIZED SUGAR.

At the beginning of this investigation it was assumed that the sugar tubes must have a relatively low resistance, not exceeding 13 inches of water or 1 inch of mercury (at 32 liters flow per minute). This limit was imposed because of the usual practice of aspirating the dusty air through the sugar tube with the lungs and exhaling into a calibrated breathing bag. As the work proceeded, a foot pump was tested for aspirating the air. It proved very satisfactory in practice, measuring the air to within an accuracy of 3 or 4 per cent, even when the sugar tube had as high a resistance to flow as 3 or 4 inches of mercury (at 32 liters per minute).

This change in method, therefore, opened up the possibility of developing more efficient filtering tubes of higher resistance, containing finely grained sugar. The following series of tests were undertaken for this purpose.

SIZES OF GRANULES IN PULVERIZED SUGAR.

Two lots of commercial pulverized sugar, purchased at different times, were analyzed for sizes by screening, the screens being of the standards specified on page 18. The results are given in Table 10.

TABLE 10.—*Screen analyses of commercial pulverized sugars.*

	Lot 1.	Lot 2.
On 20-mesh.....per cent..	0.2	0.0
20 to 30 mesh.....do....	2.0	2.2
30 to 48 mesh.....do....	9.1	4.3
48 to 65 mesh.....do....	36.9	13.0
65 to 100 mesh.....do....	11.7	33.7
100 to 150 mesh.....do....	20.7	[a] 33.4
150 to 200 mesh.....do....	12.1	.....
Through 200-mesh.....do....	7.3	13.4
Total.....do....	100.0	100.0

[a] Through 100-mesh on 200-mesh.

As shown later, the sugar through 48-mesh and on 150-mesh screens is suitable. More than 60 per cent of this size is yielded by pulverized sugar.

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TESTS WITH MIXTURES OF GRANULATED AND PULVERIZED SUGARS.

Pulverized sugar was first used in these tests in the attempt to fill the crevices between the granules of granulated sugar, thus increasing its filtering efficiency. The resistance to the flow of air through such mixtures was found to be very high; a thin, ¼-inch layer of sugar was therefore tested, giving a weight of only 20 grams in a tube 2⅜ inches in diameter. Light weight is of advantage, since it reduces the work and time needed for determination in the laboratory and the errors due to impurities in sugar. In order to retain the fine sugar in the tube, a screen of 200 meshes to the inch was placed above the stiff screen and the edges were embedded in plasticene.

The first experiment with the mixture of sugars showed that moisture in the smoke caused the thin layers to contract from the sides of the tube and to develop cracks much like mud when drying. To prevent this, the arrangement shown in figure 8 was devised. A fine screen covered by a stiff one was placed on top of the thin sugar layer; a spring above these put pressure on the sugar, stopping the warping and cracking. Table 11 gives the results of the tests.

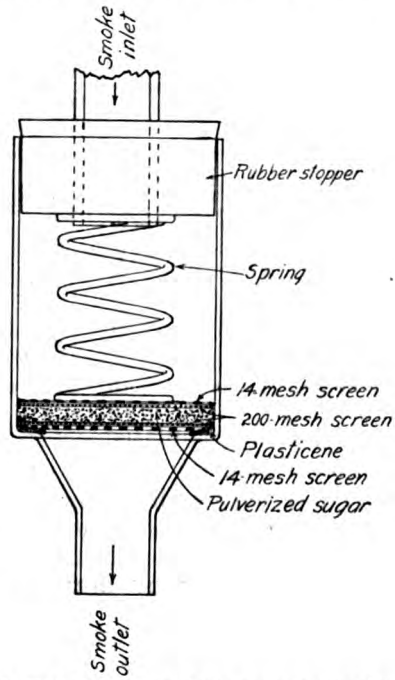

FIGURE 8.—Arrangement of screens and spring above a thin layer of pulverized sugar to prevent cracking by moisture.

Included in the table are results obtained with 100 per cent pulverized sugar in 20 and 10 gram quantities, about 0.25 and 0.1 inch depths, tested with wet smoke and smoke dried with fused calcium chloride. Results show that none of the mixtures of granulated and pulverized sugars is as good as the pulverized sugar alone. The efficiency in all cases declines with increasing use, in spite of the fact that the resistance as a whole increases. The decline seems to be caused by a stopping of the filter in parts and channeling in other parts. The maximum increase in resistance of 2.2 to 3 inches of mercury column, equivalent to 29.9 to 40.8 inches of water, was obtained in the test with dry smoke on 100 per cent pulverized sugar one-fourth of an inch deep. With wet smoke the decline in efficiency was 21 per

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cent or more during 15 minutes. The highest efficiency, 98 per cent at the beginning and 94 per cent after 15 minutes, was shown by pulverized sugar one-fourth of an inch deep.

TABLE 11.—*Results of smoke-filtering experiments with mixed pulverized and granulated sugars.*

[Pulverized sugar used without being screened, granulated sugars, 14 to 65 mesh; Bureau of Mines type B filter, 2¾ inches diameter, with screens and spring above sugar; smoke from one tobacco stick: rate of flow, 32 liters per minute.]

Mixture of sugars by weight.		Weight of sugar.	Depth of sugar.[a]	Resistance to flow, at 32 L. per minute.		Filtering efficiency.				Remarks.
Pulverized.	Granulated.			Before test.	After test.	After 2 minutes.	After 5 minutes.	After 10 minutes.	After 15 minutes.	
Per cent.	*Per cent.*	*Grams.*	*Inches.*	*Inches of mercury.*	*Inches of mercury.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
10	90	20	0.25	0.3	0.3	20–30	20–30	20–30	20–30	Wet smoke.
50	50	20	.25	.8	.9	60	40	[b] 20	[b] 20	Do.
80	20	20	.25	1.5	1.7	89	80	65	50	Do.
90	10	20	.25	1.8	2.1	92	90	80	70	Do.
100	0	20	.25	2.1	2.1	96	90	85	75	Do.
100	0	10	.1	1.3	1.5	85	78	60	50	Do.
100	0	20	.25	2.2	3.0	98	96	95	94	Dried smoke.
100	0	10	.1	1.5	1.9	89	84	80	75	Do.

[a] Figures for depth are nominal because of slight unevenness of screens. [b] Approximate.

In general, granulated sugars alone, or mixtures of granulated and pulverized sugars, are not as desirable as pulverized sugar alone. The latter, even with the small quantities used, gave efficiencies about twice as great as previously found with any granulated sugars.

EFFECT OF SIZES OF THE FINE GRANULES.

Table 12 gives the results of the tests, arranged to show the filtering powers of mixtures of sizes of pulverized sugar included between different limits. Screens and springs were not used above the sugar in these tests; it was possible to test thin layers of sugar against dry smoke because no warping and cracking occurred. The table shows that with wet smoke there is generally a small decline in resistance, but with dry smoke the resistance stays more uniform. With both wet and dry smoke efficiency declines with use, but the decline is usually greater with wet smoke.

Of the various sizes of sugars, 48 to 150 mesh, 1 inch deep, combines a moderate resistance to flow with high efficiency, with a percentage of 90 or more against wet smoke through a 15-minute period.

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TABLE 12.—*Results of experiments arranged to show the effect on filtering efficiencies of mixed sizes of pulverized sugars included between different limits.*

[Tubes, Bureau of Mines type B, 2⅜ inches diameter; top screens and spring not used; smoke, from one tobacco stick; rate of flow, 32 liters per minute.]

Size of sugar.	Depth of sugar.	Weight of sugar.	Resistance.		Condition of smoke.	Filtering efficiency.			
			Before.	After.		After 2 minutes.	After 5 minutes.	After 10 minutes.	After 15 minutes.
Mesh per inch.	*Inches.*	*Grams.*	*Inches of mercury.*	*Inches of mercury.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
65 to 200	0.5	40	2.7	2.6	Wet.	98	96	94	93
48 to 150	.75	60	2.0	1.8	Wet.	91	85	81	78
48 to 200	.75	60	2.9	2.5	Wet.	98	96	93	90
65 to 100	.75	60	2.1	2.1	Wet.	95	91	88	84
65 to 150	.75	60	2.9	2.7	Wet.	98	95	92	89
65 to 200	.75	60	3.4	3.3	Wet.	99	98	97	95
48 to 100	1.0	75	1.7	1.7	Wet.	94	92	89	87
48 to 150	1	75	2.5	2.3	Wet.	96	95	92	90
48 to 200	1	75	3.8	3.5	Wet.	98	97	96	95
65 to 100	1	75	2.2	2.2	Wet.	97	94	92	89
65 to 150	1	75	2.5	2.3	Wet.	98	96	95	94
65 to 200	1	75	3.8	4.0	Wet.	99.5	99.5	99	99
65 to 200	.25	20	1.6	1.6	Dry.	88	84	81	78
65 to 200	.38	30	2.5	2.5	Dry.	94	93	92	90
65 to 200	.5	40	3.0	3.0	Dry.	97	97	96	95
48 to 100	.75	60	1.8	1.5	Dry.	92	88	86	84
48 to 150	.75	60	2.0	1.9	Dry.	93	92	91	89
48 to 200	.75	60	3.0	2.8	Dry.	98	97	97	96
65 to 100	.75	60	1.8	1.8	Dry.	94	93	92	91
65 to 150	.75	60	2.7	2.7	Dry.	98	97	97	96
65 to 200	.75	60	3.3	3.3	Dry.	99	98	98	97
48 to 100	1.0	75	1.7	1.7	Dry.	93	91	88	86
48 to 150	1	75	2.5	2.3	Dry.	98	97	97	96
48 to 200	1	75	3.6	3.0	Dry.	99	98	98	97
65 to 100	1	75	2.2	2.2	Dry.	97	96	96	95
65 to 150	1	75	3.0	3.0	Dry.	99	98	98	97
65 to 200	1	75	7.0	.....	Dry.	[a]99.5+	.....	.....	.....

[a] Resistance too high to finish.

EFFECT OF DEPTH OF PULVERIZED SUGARS.

Comparison of the figures in Table 12, if based on the increasing depth of sugar with the mesh and other variables constant, shows an increasing filtering action with increase in depth in every case. Only one series of 65 to 200 mesh sugar at five different depths was made, using dry smoke. The comparison is shown in figure 9. With depths between one quarter and one-half inch the decline in efficiency with use was considerable and increased with decrease of depth; at one-half inch and above the decline in efficiency was only 2 per cent after 15 minutes of use.

TESTS WITH SILICA DUST.

Two tests were made with silica dust by the optical method. The tube was a Bureau of Mines type B, 2⅜ inches in diameter, holding 75 grams of 48 to 150 mesh pulverized sugar, nominally 1 inch deep. No dust whatever was visible in the effluent from the tubes in the Tyndall box. Since it was impossible to discern dust in these tests at indicated efficiencies above 98 per cent, it can only be stated that the filtering efficiency against the dust was higher than 98 per cent. This efficiency continued for a period of three minutes; afterwards

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the resistance increased beyond the capacity of the test apparatus. In practice resistance would not increase to this extent because of the very much lighter dust suspension; therefore the filters as tested will prove practicable.

TESTS WITH CALIBRATED FOOT PUMP.

The greatly increased resistance to flow of air through the pulverized sugars introduces new sources of error; the higher vacuum needed to draw air increases the probability of leakage around the piston of the pump, and the slower flow of air into the pump cylinder at the end of each stroke introduces a possibility of incompletely

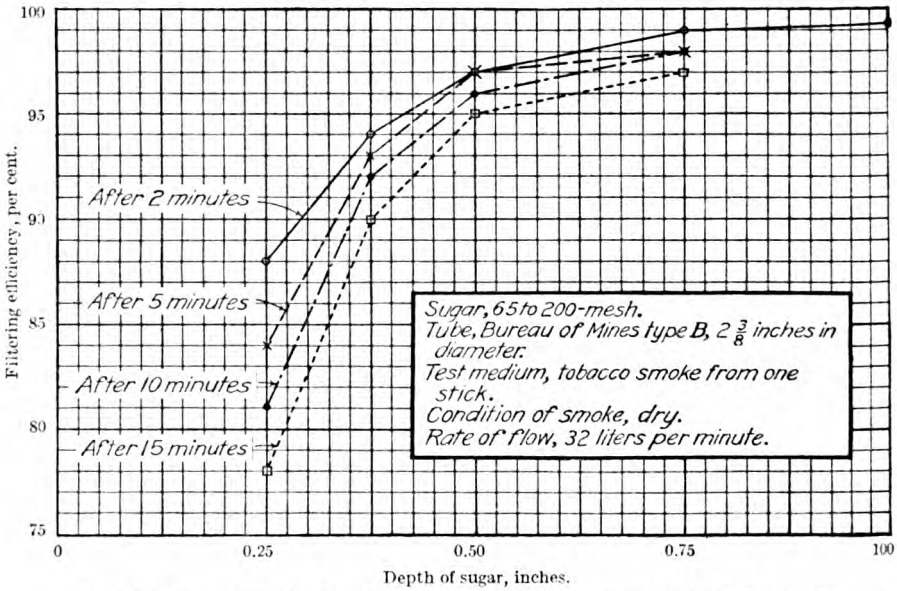

FIGURE 9.—Curves showing the relation between the depth of pulverized sugar and filtering efficiency.

filling the pump with air at atmospheric pressure before the next stroke is begun.

Experiments were therefore made to determine the accuracy of the outfit for measuring air drawn through pulverized-sugar tubes of various resistances. Notes were also taken of the physical exertion required to operate the pump at the various high resistances.

The foot pump was a "lungmotor" resuscitation pump to which suitable check valves and connections for sugar tubes were attached. The lungmotor is a double-barreled single-acting pump of aluminum and brass and is designed to give a volume of 0.05 cubic foot of air per full stroke, or 1 cubic foot per 20 strokes. For the tests with pulverized sugar, a calibrated dry meter with a negligible resistance to flow was connected to the top of the sugar tube as shown in the photograph designated as Plate II. The tube was connected, with

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APPARATUS FOR PUMPING TESTS WITH PULVERIZED SUGAR.

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noncollapsible rubber tubing of three-quarters inch inside diameter, to the pump; a mercury manometer, connected by tubing and a T, indicated the vacuum at the sugar tube. The pump discharged freely into the room. A metronome beating one-half second intervals timed the strokes of the pump as follows:

Beat 1, down stroke; beat 2, beat 3, and beat 4, upstroke, giving suction; beat 5 and beat 6, rest, holding piston at top.

That atmospheric pressure in the pump cylinder was attained at the end of each stroke was indicated by the mercury manometer and by the suction which the operator felt on the piston handle. The rate of pumping was always sufficient to allow the full measure of air, as indicated on the meter and the manometer, to pass into the cylinder. (See Table 13).

Table 13 shows that it is entirely feasible to use sugar tubes with a resistance to flow of 3 inches of mercury at 32 liters per minute, and it is probable that resistances as high as 4 inches could be used. Test 347 had a final resistance of 4 inches but the data are vitiated by a leaky valve. As far as the labor of pumping was concerned, 20 minutes of pumping at 15 cycles per minute caused no sense of being overworked to a man of average strength. Test 346, in which the resistance ranged from 4.9 to 6.2 inches of mercury, became tiresome and was stopped after 13 minutes. In this test as well a low volume of sampled air per cycle was shown, probably because of leakage around the piston. The valves seemed to work perfectly, but as they were made of thin mica disks, the strain on them was undoubtedly severe and leaks developed later. After leaks were indicated aluminum plates were substituted for the mica. Tests 483, 489, and 490 show closely agreeing pump characteristics. The average volumes per stroke for a sampling period agree to within 2 per cent, and the maximum deviation shown for a single minute is less than 9 per cent. The labor of pumping the apparatus for 15 or 20 minutes was not much in excess of that needed to operate the pump with no outside resistance to air flow, as is indicated by the operator's maximum heart beat of 100 at the end of a test period. Tests 521 and 522 were made at 30° C. in water-saturated air to determine the effect of high humidity on the work required for pumping. Pulverized sugar showed a slight decrease in resistance, but the granulated sugar showed no change.

RESULTS OF TESTS WITH LOW AND HIGH RESISTANCE TUBES IN TANDEM.

As a final comparison of efficiencies of the lower resistance granulated-sugar tubes with high resistance pulverized-sugar tubes, tests were made by the weighing method with two tubes in tandem, granulated sugar being the first to receive the dust. The weight of the

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TABLE 13.—*Results of tests with the calibrated foot pump and pulverized sugars filtering room air.*

Test No.	Sugar tube, Bureau of Mines type—	Diameter.	Sugar.		Weight.	Duration of test.	Pump cycles per minute.	Resistance to flow at 32 liters per minute.		Air filtered.		Air per pump cycle, calculated from 1-minute observations.			Cycles per cubic foot, average.	Vacuum indicated.	Pulse of operator at end.	Screens and springs above sugar.	Remarks.
			Size of granules.	Depth (nominal).				Start.	End.	Total.	Average per minute.	Maximum.	Minimum.	Average.					
		Inches.	*Mesh per inch.*	*Inches.*	*Grams.*	*Minutes.*		*Inches of mercury.*	*Inches of mercury.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*		*Average inches of mercury.*	*Beats per minute.*		
345..	B.....	2⅜	65–100	0.1	10	20	20	1.3	1.1	19.01	0.946	0.0485	0.0460	0.0473	21.1	.....	.....	Used..	Operator No.1: Changed from right to left hand in 14 min.
346..	B.....	2⅜	65–100	.2	16	13	(*a*)	4.9	6.2	8.00	.....	.0370	.0333	.0352	27.7	.....	.....	...do..	Operator No. 2: Changed hands, then used both hands; hard work; stopped.
347..	B.....	2⅜	(*b*)	.3	24	20	15	3.0	4.0	12.60	.630	.0426	.0412	.0420	23.9	.....	.....	...do..	Operator No.1: Valve leaked.
348..	B.....	2⅜	(*b*)	.2	16	20	20	2.2	2.8	17.00	.850	.....	.....	.0425	23.5	.....	88	...do..	Do.
483..	B.....	2⅜	48–150	1.0	75	15	20	2.3	2.45	14.22	.948	.0490	.0455	.0474	21.1	9.0	91	None.	Operator No. 1: Changed hands once; new valves.
489..	Metal.....	2⅜	48–150	1.0	75	15	20	2.1	2.1	14.43	.960	.....	.....	.0481	20.8	8.0	100	...do..	Do.
490..	.....do.....	2	48–150	1.0	50	15	16⅔	3.0	3.1	12.00	.800	.0510	.0438	.0480	20.8	12.0	96	...do..	Do.
521..	B.....	2⅜	48–150	1.0	75	15.25	{*c* 20⅝ *e* 17}	1.8	1.6	15.1	.....	.....	(*d*)	.051	19.6	1.6	88	...do..	Granulated-sugar tests made under same conditions as test 522; sugar was wet ½ in. down; operator was wet with perspiration at close.
522..	B.....	2⅜	14–65	1.63	100	15	20⅝	.4	*f*.4	15.86	1.057	.....	.....	.0510	19.6	6.4	90	...do..	Test made at 30° C. in atmosphere saturated with water vapor to determine effect on resistance; the sugar pulled away from sides of tubes about ⅛ in. from top.

a Varied.
b Unscreened pulverized.
c For 9 minutes.
d Assumed.
e For 6½ minutes.
f 5.4 inches H_2O.

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dust and the number of particles caught by each tube were determined, as well as the number of particles which with the filtrates passed through the close texture filter papers. Table 14 gives the results.

As indicated by the final averages in Table 14, 90.4 per cent of the weight of the dust evolved was caught by the granulated sugar and 4.5 per cent by the pulverized, with 5.1 per cent of the weight lost. Special tests were made to determine the loss of the silica dust by volatilization during ignition. No such loss was shown. Although no silica dust was visible on the 280-mesh screen used (some matter from the sugar was caught), special tests by igniting and weighing the screen-caught matter definitely proved no loss of dust there. The only remaining source of loss is through the filter papers. It is not practicable to determine the small weight of dust known to be present in the filtrate, but the loss of 5.1 per cent may be safely assumed to be there. The granulated sugar, catching 90.1 per cent of the weight of dust evolved, is satisfactory to the extent that the additional 4.5 per cent weight caught by the pulverized sugar would hardly justify a change because of this consideration alone.

On a basis of the total numbers of particles recovered, 75.2 per cent were caught by the granulated and 24.8 per cent by the pulverized sugars. This result shows the pulverized sugar to be much more efficient in catching the very small particles which are large in number, but negligibly small in weight.

It is still a question whether the number of these minute particles is more important from a hygienic standpoint than their mass. That point may be finally decided later, however. At present, it seems advisable to use pulverized sugar for dust sampling.

GENERAL DISCUSSION OF RESULTS OF TESTS.

The tests described in this paper have dealt with very small quantities of particles in an extremely fine state of division. The difficulties of accurate manipulation and observation have been considerable, hence, variations due to nonuniform packing of sugar in the tubes, channeling, and filling of interstices with the deposited dust during a determination have produced material variations in the individual tests. Nevertheless the average results of series of measurements show definite tendencies from which conclusions can be drawn.

In the optical tests with silica dust the efficiencies of the sugar tubes increased as the tests proceeded; in some instances where rather dense clouds were used, the increase was from 46 per cent to 91 per cent in three minutes from the start of the test, the increase being much less with very dilute clouds of dust. Since in practice it is important that sugar tubes retain as much as possible of the dust when in very dilute suspension, the figures obtained before the

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TABLE 14.—*Comparative efficiencies of granulated and pulverized sugars against silica dust, determined with tandem tubes.*

Granulated sugars, 14 to 65 mesh, used without screening, 100 grams in glass tubes of 2¾ inches diameter, 1⅝ inches depth; pulverized sugars, 48 to 150 mesh, 75 grams in metal tubes of 2⅜ inches diameter, 1 inch depth.]

Dust evolved.	Dust recovered.																			
	Weight.																			
	By granulated sugar.									By pulverized sugar.									Total.	
	Over 10 diameter.			Under 10 diameter.			Total.			Over 10 diameter.			Under 10 diameter.			Total.			Mg.	Dust evolved.
	Mg.	Dust recovered.	Dust evolved.	Mg.	Dust recovered.	Dust evolved.	Mg.	Dust recovered.	Dust evolved.	Mg.	Dust recovered.	Dust evolved.	Mg.	Dust recovered.	Dust evolved.	Mg.	Dust recovered.	Dust evolved.		
Mg.		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*
.....	1.2	41.4	.....	1.7	58.6	.....	2.9	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.9	.....
.....	1.2	41.4	.....	1.7	58.6	.....	2.9	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.9	.....
.....	1.2	41.4	.....	1.7	58.6	.....	2.9	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.9	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.7	33.3	.....	1.4	66.7	.....	2.1	100	.....	2.1	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.5	33.3	.....	1.0	66.7	.....	1.5	100	.....	1.5	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.6	33.3	.....	1.2	66.7	.....	1.8	100	.....	1.8	.....
39.1	17.8	53.3	45.5	15.2	45.5	38.9	33.0	98.8	84.4	.3	.9	0.8	.1	.3	0.2	.4	1.2	1.0	33.4	85.4
14.0	6.7	54.0	47.8	5.3	42.7	37.8	12.0	96.7	85.6	.3	2.4	2.1	.1	.8	.7	.4	3.2	2.8	12.4	88.4
97.6	3.8	40.0	39.2	5.1	53.7	52.6	8.9	93.7	91.8	.2	2.1	2.1	.4	4.2	4.1	.6	6.3	6.2	9.5	98.0
2.6	1.4	59.0	53.8	1.2	42.9	46.1	2.6	92.9	99.9	.0	.0	.0	.2	7.1	7.7	.2	7.1	7.7	2.8	107.6
.....	.....	49.3	46.6	.....	46.2	43.8	.....	95.5	90.4	.....	1.4	1.3	.....	3.4	3.2	.....	4.8	4.5	.....	94.9

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Dust recovered. Numbers. By granulated sugar. Over 10 diameter. Millions.	Over 10 diameter. Dust recovered.	Under 10 diameter. Millions.	Under 10 diameter. Dust recovered.	Total. Millions.	Total. Dust recovered.	By pulverized sugar. Over 10 diameter. Millions.	Over 10 diameter. Dust recovered.	Under 10 diameter. Millions.	Under 10 diameter. Dust recovered.	Total. Millions.	Total. Dust recovered.	Total. Millions.	Total. Dust recovered.	Dust lost. Weight. Mg.	Weight. Dust evolved.	Numbers in filtrates under 10. From granulated. Millions.	From granulated. Dust recovered.	From pulverized. Millions.	From pulverized. Dust recovered.	Total. Millions.	Total. Dust recovered.	Remarks.
	Per ct.		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*	
1	1.4	72	98.6	73	100	.....	.....	.....	.....	.....	.....	73	100	.....	.....	15	20.5	.....	.....	15	20.5	Blank test of 100 grams of granulated sugar.
1	1.5	66	98.5	67	100	.....	.....	.....	.....	.....	.....	67	100	.....	.....	.....	.....	.....	.....	.....	.....	Do.
1	1.5	69	98.5	70	100	.....	.....	.....	.....	.....	.....	70	100	.....	.....	.....	.....	.....	.....	.....	.....	Average of blanks from granulated sugar.
.....	.....	.....	.....	.....	.....	1	1.6	60	98.4	61	100	61	100	.....	.....	.....	.....	20	32.8	20	32.8	Blank test of 75 grams of pulverized sugar.
.....	.....	.....	.....	.....	.....	1	1.8	54	98.2	55	100	55	100	.....	.....	.....	.....	.....	.....	.....	.....	Do.
.....	.....	.....	.....	.....	.....	1	1.7	57	98.3	58	100	58	100	.....	.....	.....	.....	20	32.8	20	32.8	Average of blanks from pulverized sugar.
23	1.2	1,653	87.0	1,676	88.2	3	.2	220	11.6	223	11.8	1,899	100	5.7	14.6	575	30.3	205	10.8	782	41.2	1,000,000 particles above 10 were found in filtrates from the granulated and the pulverized sugars.
12	1.0	1,000	84.4	1,012	85.4	1	.1	172	14.5	173	14.6	1,185	100	1.6	11.6	118	10.0	23	1.9	142	12.0	1,000,000 particles above 10 were found in filtrates from the granulated sugars.
5	.6	492	55.8	497	56.4	3	.3	381	43.3	384	43.6	881	100	.2	2.0	203	23.7	9	1.0	218	24.7	
3	.9	239	69.9	242	70.8	1	.3	99	28.9	100	29.2	342	100	+.2	+7.6	68	19.9	15	4.4	83	24.3	
.....	.9	.....	74.3	.....	75.2	.....	.2	.....	24.6	.....	24.8	.....	100	.....	5.1	.....	21.0	.....	4.5	.....	25.5	Averages.

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clogging takes place should be used for comparison. In the weighing tests the dust evolved was small enough to produce only a negligible clogging; hence the efficiencies formed may be taken as those of the sugars themselves. Tobacco smoke, on the other hand, consists of fairly uniform particles of a smaller order of magnitude than the silica dust and affords a testing medium that does not clog the sugar as rapidly. It gives a better means than silica dust of rating the efficiencies of the sugar tubes for very small particles, especially on the basis of numbers, as with the smoke particles of uniform size the optical efficiency also measures the numerical efficiency.

LOW RESISTANCE TUBE WITH GRANULATED SUGAR.

When the results of the tests are considered from the above points of view, it may be stated that the new Bureau of Mines sugar tube, designated as type B, represents one of the most practicable and efficient styles of tube possible with granulated sugar containing no finer granules than 65-mesh. The relatively large amount of sugar—100 grams—that is necessitated by a tube 2⅜ inches in diameter, introduces more tedious manipulation in dissolving and filtering, but this extra work is necessary to get adequate filtering results with low resistance to the flow of air.

On a weight basis with silica dust this tube has an efficiency of 75 to 95 per cent, depending upon the degree of packing and the humidity of the atmosphere. On the basis of numbers the optical tobacco-smoke tests are the best criteria for the very smallest particles; relatively, a negligible weight of these particles which border on the ultramicroscopic in size produces a distinct effect in the Tyndall beam. It may be considered that the practical number efficiency of a sugar tube is certainly not less than the 40 to 60 per cent found with smoke and is probably in the region of 75 per cent, as indicated by the tests with tandem tubes.

Everything finally considered, it appears safe to conclude that the number efficiency of the type B tube ranges between 40 and 60 per cent for very fine particles of the nature of tobacco smoke, these figures including particles finer than can be counted under the microscope as ordinarily used for this purpose; 60 to 85 per cent represents the number efficiency of the tubes as used in practice. On the weight basis the present low-resistance granulated sugar may be considered satisfactory for measuring the dustiness of air, since at least 75 per cent and usually 90 per cent or more of the dust is caught. On the numerical basis it fails to retain a sufficient quantity of fine particles to be entirely satisfactory. Obviously, finer-grained sugar with a higher resistance to flow must be used to obtain satisfactory measurements of numbers.

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HIGH-RESISTANCE TUBE USING PULVERIZED SUGAR.

The experiments previously described have shown that with fine-grained pulverized sugar it is possible to filter from air practically all the particles that are large enough to be counted under the microscope. Even with tobacco smoke, 50 to 75 grams of 48 to 150 mesh sugar in a 2⅜-inch tube will give from 80 to 95 per cent optical efficiency. This figure corresponds to the 98 per cent or more efficiency as determined by optical tests with silica dust and may be safely taken as 100 per cent efficiency on a number of particles basis in actual practice.

Tubes of pulverized sugar have not yet been given a thorough trial in the field. Possibly some trouble may occur from clogging and shrinking of the sugar when it is used in very humid atmospheres. However, with experience and further trial, it is hoped that any such difficulties may be overcome and that a tube may be perfected that eventually retains all the dust aspirated into it.

SUMMARY AND CONCLUSIONS.

The determination of dust in the air of mines by the method now in use by the Bureau of Mines involves filtering a measured volume of air through a layer of granulated sugar; in the laboratory the sugar is then dissolved, filtered through close-texture paper, washed, the paper and dust ignited, and the incombustible matter weighed. A blank is subtracted for the sugar and other substances. The remainder represents the dust. The number of dust particles is also determined by counting those in a small volume of the sugar solution under a microscope.

The efficiency of sugar as a filter was investigated by two methods. The first consisted in passing tobacco smoke or silica dust suspended in air through the filter. Two streams of dust, one from the air entering the filter—"incoming" dust or smoke—and the other from the air leaving the filter—"outgoing" dust—were compared in a beam of light in a Tyndall box. By diluting the incoming dust or smoke stream in the Tyndall box with measured amounts of pure air until it matched the outgoing stream, a means of quantitatively determining the efficiency of the filter was obtained. The second method of testing consisted in generating clouds of silica dust from a small weighed amount of dust and filtering the suspended dust through sugar filters. Loss in weight of the original dust was then determined and compared with the weight from the sugar after dissolving, filtering, washing, igniting, weighing, and subtracting the blank.

The principal conclusions from the investigation are these:

1. The filtering efficiency of sugar tubes increases with increase in the diameter of the tubes. Various tests made with tobacco smoke to compare tubes of 1½ and 2⅜ inches diameter showed efficiencies

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between 23 per cent and 60 per cent, with an average difference of 13 per cent in favor of the wider tube.

2. The rate of flow of air through unit cross sections of a sugar tube is smaller as the tube increases in diameter; hence from the first conclusion it may be stated that the efficiencies of the filters decrease as the rate of air passage increases.

3. The effect of wetting sugar with water or with 35 per cent alcohol and testing it optically against silica dust shows an average increase of 4 per cent for the water and 5 per cent for the 35 per cent alcohol over comparative efficiencies of dry sugar. Averages for similar tests indicate a minimum efficiency of 57 per cent with dry filters after one-half minute of use, and a maximum of 94 per cent for wet sugar after three minutes of use.

4. Sugars of different sizes, tested with tobacco smoke, show an increased filtering efficiency with increasing fineness. For example, when a tube 2⅛ inches in diameter is used, the efficiency ranges from 27 per cent for sugar from 20 to 35 mesh to 60 per cent for sugar from 48 to 65 mesh, while pulverized sugar of 48 to 150 mesh sizes gives over 90 per cent efficiency.

5. Experiments with tobacco smoke to demonstrate the effect of increasing the depth of granulated sugar on the filtering efficiency show efficiencies of 14 per cent for a 1-inch depth and 38 per cent for a 4-inch depth. The effect of the increasing depth grows less as the height increases.

6. Sugar contains considerable amounts of insoluble noncombustible matter compared to the weight of dust in samples, and the amounts vary for different lots of sugar; hence it is necessary to run blanks for every lot and it is advisable to run blanks with each set of samples.

7. Tests by the method of weighing silica dust before and after producing clouds and passing them through filters, then of recovering and weighing the dust caught by the sugar, show efficiencies of dust recovery ranging from about 70 per cent to 95 per cent.

8. Microscopic examination of sugar solutions which had passed through C. S. & S. blue ribbon paper filters, very close in texture, shows an appreciable loss of silica dust which has passed through the filter.

9. Tests by the weighing method show higher efficiencies for sugar tubes than tests by the optical method of testing with silica dust, probably because the finer dust passes through the sugar tubes. The optical method is based on the reflection of light from the dust surface. The surface of the finer dust is greater than the corresponding weight, so that a lesser efficiency is indicated by the optical method.

10. A sugar tube containing 65 grams of pulverized sugar, 48 to 150 mesh size, was found to give over 92 per cent efficiency against wet tobacco smoke for 15 minutes.

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